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CONTRIBUTION FROM THE GEOLOGICAL DEPARTMENT OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY, CAMBRIDGE, MASS.

THE GRANITES AND PEGMATITES OF CAPE ANN, MASSACHUSETTS.

By Charles H. Warren and Hugh E. McKinstry.

With Five Plates.

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CONTENTS.

INTRODUCTION.

THE igneous rocks of New England have been the subject of study from a number of localities and the results obtained have furnished petrologists with material of considerable interest and importance including a knowledge of several new rock types. The glaciated island of Cape Ann (Plate I shows the location of Cape Ann on the New England coast and also the distribution of the principal formations in eastern Massachusetts), with its margin bared by wave erosion and its extensively exploited quarries, offers exceptional opportunities for the study of the rock types found there. Attention was long ago

directed to the locality both because of the commercial importance of the granites and the mineralogic interest of the minerals found in the granites and associated pegmatites.

It is the purpose of the present paper to describe the more important types of granitoid igneous rocks and the pegmatites exposed on the island of Cape Ann, to note their field relations and to discuss in so far as the facts available warrant, the history of the intrusion of these rocks and their genetic relations.

In stating the facts herein set forth, the authors have drawn freely on the publications of previous workers in this field. They have, however, gone over the entire area personally and have restudied the various rock types in the laboratory and while many of the statements regarding petrographic details may be found elsewhere, the attempt has been made to present a comprehensive statement of the petrology of the entire area and to add to preëxisting data considerable new material, particularly with regard to the relation of the various types. Earlier work on the area appears to have left much to be desired in this latter respect.

The rocks here described form a part of a great intrusion of igneous rocks which appear to have originated simultaneously, or approximately so, at a considerable number of points throughout New England and adjoining parts of Canada, and which taken together have been appropriately designated as the "Novanglian Petrographic Province" by Washington and Pirsson.[1] The rocks are in the main granitoid types, but in part also of porphyritic or other texture. The latter are in the main intrusive as dikes, or occur as marginal phases; some of them are extrusive in character. They are predominately high in silica, alkalies and ferrous iron. Lime is in general subordinate while the magnesia is conspicuously low.

These rocks are intrusive through an older series of granite, diorites and gabbros and their associated sedimentary rocks, quartzites, schists, etc. They are overlaid in the immediate vicinity of Boston by carboniferous rocks, conglomerates, slates and the contemporaneous volcanics. They may be of late Devonic or early Carboniferous age.

Many trap dikes, mostly if not entirely diabasic in character, and possibly of Triassic age, cut all of these rock formations.

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[1] See Amer. Jour. Sci., vol. 22, p. 514, 1906.

PART I.

Granitoid Rocks of Cape Ann, Mass.

Previous Geologic Work.

The rocks of Cape Ann first attracted scientific attention on the mineralogic side. In 1866–67 and again in 1886 Cooke [2] two new mineral species from the Rockport pegmatites. Throughout the mineralogical literature of the period are scattered references to the granitic rocks, notably Wadsworth's [3] description of the biotite and hornblende granites — the latter he described as syenite, in accordance with the older nomenclature. Sears' geologic map in 1895 was accompanied by a description of certain rock types. Shaler,[4] in 1899, published a description of the glacial features of Cape Ann, together with a detailed study of the location of the dikes and joint planes in the granite and a brief description of the igneous rocks.

However, the first modern study of the igneous rocks of the district was published by H. S. Washington [5] in 1898. This admirable piece of work is primarily concerned with the petrographic description of the various rock types found in the general region about Salem, Massachusetts, Marblehead, and the North Shore as far as, and including, Cape Ann. While adding some field observations of his own, he in the main accepts the field relations as given by Sears [6] in his map of the region published somewhat later. Unfortunately, Sears' map is unreliable. Washington established beyond doubt the consanguinity of the rocks studied and the general similarity of the rocks to other alkaline types, not only in New England but to types occurring in Norway and described by W. C. Brogger in his classic papers.

Clapp,[7] in 1910, described the general relations of the igneous rocks of Essex County, devoting detailed study to a special area which did not include, except by incidental reference, Cape Ann. He regards

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[2] Cooke, J. P. Danalite, a New Mineral from Rockport, Mass. Amer. Jour. Sci., vol. 42, p. 73, 1866. Cryophyllite and Associated Minerals from Rockport, Mass. Amer. Jour. Sci., vol. 43, pp. 217–230, 1867.

[3] Wadsworth, M. E. Notes on the Petrography of the Quincy and Rockport Granite. Proc. Bost. Soc. Nat. Hist., vol. 19, p. 309, 1867–78.

[4] Shaler, N. S. Geology of Cape Ann, Massachusetts. Ninth Annual Report U. S. G. S. pp. 529–611, 1899.

[5] Washington, H. S. The Petrographic Province of Essex Co., Mass. Amer. Jour. Sci., vols. 6–7, 1899. (Several numbers.)

[6] Sears, J. H. The Physical Geography, etc., of Essex Co., Mass. 1905.

[7] Clapp, C. H. Igneous Rocks of Essex County, Mass. Manuscript Thesis, Mass. Inst. Technology, 1910. Also U. S. G. S. Bull. 704, 1921.

the nordmarkitic granite (quartz-syenite) as a marginal differentiate of the granite magma and considers the fine-granite and pegmatite as apophysal phases of the final granite intrusion. His data on Cape Ann are based partly on a reconnaissance of the area made by Maxwell and Chipman.[8]

Field Relations.

By far the greater portion of the district is underlain by the Rockport, or normal, granite. The only other rock which occupies any considerable area is the nordmarkitic granite, which so far as we have been able to discover, occurs chiefly along the west coast of the Cape, extending from Squam Light to a short distance north of Lanesville. Besides this narrow strip, a small area, not more than fifteen meters wide, of dark coarse-grained rock occurs surrounded by the granite on Andrew's Point on the extreme end of the Cape. North of Rockport to Andrew's Point small areas of nordmarkitic granite are exposed along the coast and there is a somewhat poorly defined area on Briar Neck near Gloucester.

The nordmarkitic granite alone the west coast could not be traced far inland. Along a valley between Bay View and Lanesville it extends eastward about half a mile from the coast, but farther inland large granite quarries show none. The general absence of exposures of the rock inland may be due not so much to its actual absence as to its relative ease of disintegration which would cause it to be covered with a mantle of soil, while the granite, which everywhere intrudes it, would stand out in bare knobs. The comparative instability of the nordmarkitic phase under weathering is very apparent in the glacial moranes, where boulders of the granite appear fresh, while the other shows an advanced state of disintegration. Yet the continuous exposures of rock along the coast from Folly Cove around Halibut Point to Pigeon Cove show practically no nordmarkitic granite nor is any exposed in any of the numerous quarries, except in the form of altered inclusions. Thus, there are large areas over which the rock does not occur.

Along the west shore, from Squam Light to Folly Cove, the relations of the nordmarkitic phase to the granite are very clearly shown. The nordmarkitic phase is cut by an irregular system of dikes ranging from a few centimeters to three meters or more in width. These dikes con-

8 Chipman, K. G., and Maxwell, J. W. Geology of the Cape Ann Granite. Manuscript Thesis, Mass. Inst. Technology, 1908.

sist of granite, fine-granite, and aplite, branching in intricate patterns, and in places the granite is the more abundant of the two rocks, the nordmarkitic rock occurring in the form of angular included blocks. The penetration is so complicated that it is impossible to draw a line between areas of the nordmarkitic granite intruded by granite and areas of granite carrying inclusions, hence boundary lines must be somewhat arbitrarily located. Large inclusions in granite may be seen in vertical sections in a low cliff about half a mile north of Lanesville (Plate III, Figs. A and C) where three large blocks are surrounded on both sides and below by granite. Along the west coast, both rocks are cut by veins of fine-granite, passing into aplite and pegmatite.

Between Rockport and Andrew's Point nordmarkitic granite is exposed along the coast, in the cut along the road, and on the hill above. It occurs here associated with normal granite, a fine-grained porphyritic granite and fine-granite. Contacts here are not sharply defined, and no convincing evidence was here found to show whether or not the nordmarkitic portions were inclusions.

Three-fourths of a mile north of Bay View, a dike of light colored granite cuts the nordmarkitic granite with straight, sharp walls, and in one place sends out a well-marked tongue. This dike graded into fine-granite and at the center bears a large mass of bluish quartz.

At a number of places along the west coast, the nordmarkitic granite contains large angular blocks of a dike rock which usually carries abundant and very large phenocrysts of a dark purple labradorite. These are commonly 6 to 10 cm. long by 2 to 5 cm. wide; one crystal 25 cm. long and 10 to 15 cm. was observed. These porphyry inclusions are elongate in form and usually have two parallel straight walls. There appears to be little doubt but that they are sections of an old dike torn apart by subsequent movement of the nordmarkitic granite into which the dike was intruded. They are cut by dikes of granite and fine-granite which also cut the nordmarkitic phase. (See Plate IV, Figs. A and B).

The relations of the rocks so far described are quite clear. Nordmarkitic granite is cut by basic dike rocks. These are both cut by the granite, fine-granite, and the latter phases, aplite and pegmatite. On Davis Neck, however, a new factor enters. The nordmarkitic granite, as elsewhere, is cut by fine granite and pegmatite, but contains large masses of fine-granite containing areas of pegmatite. A few small masses of fine-granite are entirely surrounded.

Passing to the east shore, we find similar relations on Andrew's Point.

(See Plate II.) The fine-granite here contains much pegmatite, not in dikes, but forming irregular masses of coarse feldspar and bluish quartz. The contact between normal granite and fine-granite (and its pegmatitic phase) is irregular, but essentially a plane surface, dipping eastward, the fine-granite passing below the normal granite and being exposed where the overlying rock has been removed by wave erosion. Farther north, the fine-granite takes on a coarser and less siliceous character, perfectly continuous with the fine-granite to the south, and, like it, containing small areas of pegmatite. In the coarser, more syenitic phase are dikes of a black, highly biotitic dike rock, faulted and torn apart like those on the western coast. (See Plate IV, Fig. C.) The fault planes show no trace of fracture nor shear zones, but are perfectly sealed, indicating that either the faulting took place while the granite was somewhat plastic or that there was reheating subsequent to the intrusion. The basic rock dike is cut by pegmatite veins and in one place a tongue of fine-granite extends into the basic rock.

Both the fine-grained syenitic granite and the basic dikes are cut by a well-defined dike of coarse normal granite five feet wide, having gneissic texture along the margins. One of the basic dike-masses is cut in two by the granite and portions of it abut against the granite dike on both sides. Following the granite dike northwestward, it ends at the contact between fine and normal granite, the latter being lithologically similar to the dike. The contact is nearly vertical and is marked by joint planes, so that it is impossible to tell whether the dike extends uninterruptedly into the main body of the granite or is cut off by a fault.

Other Rocks in the Area, chiefly Later Dike Rocks.

Besides the above-described rocks, all of the rest are dike rocks of clearly later age than the granites, etc. The greater proportion are diabases and these are very numerous indeed as may be seen by a glance at the map made by Tarr and published in Shaler's monograph. They are perhaps of Triassic age and have so far as known no immediate genetic connection with the alkaline rocks.

The huge labradorite porphry dike, occurring at Pigeon Cove, together with one or two other smaller dikes of the same character appear from field relations elsewhere in the adjoining regions where similar dikes occur to be earlier than the diabase dikes. They are

the same rock petrographically as the inclusions found in the nordmarkitic granite on the west coast, from which it appears that the magma which gave rise to them was present and was intruded both before and after the intrusion of the alkaline granites. These labradorite porphyry dikes will be described more in detail in a later paper.

Washington has described several dike rocks belonging to the alkaline suite. His solvsbergite from near Andrew's Point, Pigeon Cove and elsewhere, and tinguiaite from near Squam Light, represent the acid pole of a complementary series to which there are doubtless complementary basic dikes among the very many dark dikes which occur in the area. These occur frequently outside the area to the south in Manchester and Salem. Some of these have been described by Washington, Clapp and MacKenzie, in papers already referred to.

There are also in the area several quartz-porphyry dikes which are not, so far as they have been studied, closely related to the alkaline rocks. The most interesting of these occurs on Briar Neck and is remarkable for the inclusion of a basic rock which it contains.

Petrographic Descriptions.

Cape Ann Granite.

This rock, which is the normal granite of the area, has been described in detail by Washington [9] so that its characteristics are well known to petrographers. The present description is given mainly for the sake of completeness, but also to bring out certain additional facts regarding this rock which are of interest particularly with reference to the associated rocks.

While the granite is quite uniform throughout the extensive exposures over the island, it is seen in its most typical form in the large quarries near Pigeon Cove and on the Babson Farm near the extreme end of the Cape. Megascopically it is a medium-grained (5 mm.) hornblende granite of a mottled gray color when fresh. It is on the whole even-grained but with a suggestion of a porphyritic texture.

The minerals are: pearly white or gray alkalic feldspar (66.0%); gray or bluish to smoky quartz (27.0%); black shiny hornblende (7.0%), associated with which is often a variable amount of black mica. Locally there are variations: the dark minerals may be almost absent, the quartz more abundant and the grain finer; the color may be dis-

[9] Washington, H. S., op. cit., pp. 769–794.

tinctly greenish (Bay View), the dark minerals more abundant, the quartz less, thus grading toward nordmarkite or syenite.

The weathering varies with the location. Inland, the feldspar kaolinizes, the hornblende develops limonite, and we get a whitish rock with a brown staining and a rough surface; near the coast, where the salt water acts on it, the dark minerals weather out completely, leaving a slightly pitted but otherwise smooth surface.

The rock makes a strong, very durable and handsome building stone. Its smooth or polished surfaces do not, however, possess the pleasing character of the Quincy granite.

Microscopically, the granite consists essentially of a microcline-albite microperthite, quartz, an alkali-hornblende and lepidomelane. The accessory minerals are: hedenbergite, fayalite, magnetite, ilmenite, zircon, apatite (rare), allanite (very rare), and fluorite; secondary minerals are: kaolinite and limonite.

The main part of the feldspar consists of an intergrowth in about equal proportions of microcline and a plagioclase very near albite. (See Plate V, Fig. C.) The crystals are commonly twinned after the carlsbad, less commonly after the Mannebach law, and are rectangular in habit although the outlines are always minutely irregular. The potassic member commonly shows the characteristic microcline structure adjacent to the albite lammellae, though it is often untwinned. It shows some incipient kaolinization and many minute cavities.

The quartz is wholly xenomorphic, generally shows an undulatory extinction or else is broken down into a mosaic. It usually contains fluid inclusions.

The hornblende is clearly a soda-iron variety, as shown by its optical properties and by the analysis of the rock as a whole. Its optical properties as given by Washington and confirmed by us are: a bright yellowish-green to light brownish-yellow; β dark greenish-brown; γ dark olive green. Absorption, $\gamma = \beta > \alpha$; the extinction $\gamma \wedge C'$ about 30°; optic angle small; optically negative. Its grains are commensurate with the feldspar, but usually have extremely ragged edges with numerous attached shreds of biotite. The biotite extends out into the feldspars, strings of flakes following along fractures away from the hornblende. Some of the hornblende appears to have been very strongly attacked by mineralizing solutions and re-crystallized into columnar or radiating aggregates which are associated with more or less biotite. There has doubtless been a removal of the hornblende substance during the process since quartz and biotite often appear in the centers of the hornblende areas and they are at

times almost or entirely replaced. The recrystallization has to some extent been accompanied by a change in composition for the γ-ray often assumes a strong blue color with a smaller extinction angle. Occasionally an irregular core of pyroxene, hedenbergite, may be seen in the hornblende; also magnetite and less often fayalite.

Most of the mica of the rock seems to be a secondary biotite, but there are occasionally large crystals which may be primary. It is closely similar to the lepidomelane of the pegmatites.

Hedenbergite and fayalite have been referred to above as present in the hornblende. Both occur rarely as separate crystals of early formation. They appear to be the same minerals that occur in the nordmarkitic phase where they are much more important constituents (see beyond). Clapp mentions diallage and glaucophane, and Washington also refers to a blue amphibole in the granite of Eastern Point, Gloucester, and at Magnolia. We have not been able to confirm the presence of diallage.

A striking feature of the granite is the fine material interstitial to the feldspar crystals. (See Plate V, Fig. C.) It is of granular texture and the grains rarely exceed 0.1 mm. in diameter. The material consists partly of quartz and partly of albite. Where contacts between grains of microperthite are invaded, the microcline member seems to be more readily replaced while the albite plates extend out into the interstitial matter. More rarely the finely granular material is not confined to the boundaries of the feldspars, but occupies narrow areas extending into the microperthite crystals. The texture of these fine-grained areas and seams is strongly suggestive of replacement.

The fine-grained material just described, taken in connection with the straining and granulation of the quartz and the alteration of the hornblende, fayalite, etc., seem to the authors to indicate quite clearly that there was movement in the granite during or immediately following the later stages of consolidation. While the temperature was still high, the residual liquors still present, a period obtained in which reactions, replacements, and recrystallization took place. This action occurred chiefly along the crystal boundaries and along the minute fractures or openings caused by slight movements in the mass as a whole.

A chemical analysis [10] of a specimen taken from the large quarry

10 The expense of this analysis as well as that of the other new analyses recorded in this paper was defrayed from a grant made to the senior author from the Bache Fund of the National Academy of Science. The authors desire here to express their thanks to the Academy for this grant.

on the Babson Farm near the end of the Cape has been made for the authors by Professor R. S. Hamilton and is given below together with the well-known analysis by Washington. For comparison there is also given the analysis of the Quincy, Mass., granite by Warren.[11] The specimen analyzed is, in our opinion, very fairly representative of the greater bulk of the granite of Cape Ann. It is notably lower in silica than that analyzed by Washington which came from the large pit of the Rockport Granite Company's quarry near Pigeon Cove. A good deal of the granite in this quarry is, we believe, as a result of our observations, more quartzose, as its analysis indicates, than the general average of the granite of the island as a whole.

Chemical Analyses.

	I	II	III
SiO_2	72.56	77.61	74.86
TiO_2	.25	.25	.20
ZrO_2	n.d.t.	n.d.t.	.20
Al_2O_3	13.21	11.94	11.61
Fe_2O_3	.78	.55	2.29
FeO	2.14	.87	1.25
MnO	.05	tr.	.02
MgO	.12	tr.	.05
CaO	.89	.31	.41
Na_2O	3.82	3.80	4.30
K_2O	5.53	4.98	4.64
H_2O+	.25	.23	.31
H_2O-	.04	tr.	.04
P_2O_5	tr.	tr.	tr.
	99.64	100.54	100.18

I. Hornblende-granite, Quarry on the Babson Farm near the Beacon. Cape Ann, Mass. L. H. Hamilton, Analyst.

II. Hornblende-granite, Rockport Granite Company's quarry, Cape Ann, Mass. H. S. Washington, Analyst.

III. Hornblende-granite, Quincy, Mass. C. H. Warren, Analyst.

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[11] Warren, C. H. Proc. Amer. Acad. of Arts and Sciences, vol. 49, p. 227, 1913.

In the quantitative classification the Cape Ann granite falls into the same groups as does the Quincy, viz., Class I, Order 4, Rang 1, Subrang 3. Comparing I and III, while they are obviously alike in type, it may be noted that the total iron is much lower in the Cape Ann granite, and that ferrous iron predominates in the Cape Ann rock, the ferric in the Quincy. The total alkalies are slightly greater (9.35% to 8.94) and the ratio K_2O/Na_2O is 0.96 in I and 0.75 in III, that is to say, the Rockport granite is distinctly more potassic. The lime is higher in I, due doubtless to the presence of some hedenbergite.

The approximate mineral composition of I, II, and III is as follows:

Mineral	I	II	III
Quartz	27.0	35.8	32.1
Microcline	32.8	29.5	27.2
Albite, ab + an	33.2	32.7	34.1
Hornblende, etc.	7.0	2.0	6.6
	100.0	100.0	100.0
Total feldspar	66.0	62.2	61.3

The Cape Ann granite is probably on the average a somewhat less quartzose rock than the Quincy, and is somewhat higher in feldspar. It contains about the same proportion of dark minerals, although these are of different kind, the Quincy granite containing only a riebeckitic hornblende and acmite.

Bay View Granite.

This variation, known commonly as the "Rockport green-granite" is developed in several places on the island and appears to grade gradually into the more normal type. Its largest and best exposed development is on the west side of the island near Bay View. It differs from the Cape Ann granite in appearance chiefly in its color which is distinctly greenish after a brief exposure to the air. It is rather gray than green when freshly broken from large blocks well within the quarry. Its further weathering is so like the regular granite that it cannot be distinguished megascopically from the latter.

Microscopically it is seen to contain less quartz, more hedenbergite and hornblende, but is otherwise quite similar. It is intermediate in many respects between the normal granite and the nordmarkitic phase.

Nordmarkitic Granite.

We give next a description of a type which grades on the one hand toward the normal granite and on the other toward an alkali-syenite. Although in general somewhat richer in quartz, and a little coarser in grain, it resembles in color and in its mineralogy the nordmarkite from Ascuteny Mt., Vt., described by Daly.[12] Clapp has also termed it a nordmarkite. Locally quartz is lacking and the rock is then an alkali-syenite. This rock is of earlier origin than the granite, since the latter cuts it. Washington [13] has described a variation of it lower in silica from near Gloucester as an akerite, and states that, in his opinion, it is about as abundant as the granites in Essex County. We are inclined to differ with him. Certainly so far as Cape Ann is concerned it is distinctly subordinate to the more quartz-rich type. He apparently includes all of what we have here called nordmarkitic granite under akerite. It should be noted here that this rock is quite distinct in occurrence, constitution and appearance from the nordmarkite described by Washington [14] which occurs typically in West Gloucester at Wolf's Hill and to the west of Annisquam.

The nordmarkitic granite is characterized by a greenish-gray color on fresh surfaces, but on exposure it assumes a dull green color which is characteristic. It is of medium to rather coarse grain, and commonly has a very distinct tendency toward a porphyritic texture. The quartz is dark, even oily in appearance, and is distinctly less in amount than in the normal granite. The dark minerals are more abundant. What has been written about the feldspar of the granite applies without essential change to this rock. There is the same extreme raggedness of crystal boundaries and the same interstitial granular material, except that in this rock this material is larger in amount and is in part a true groundmass whose original texture is complicated, and in part destroyed, by movement and granulation and probably by replacement.

The dark minerals are hedenbergite, an alkali-hornblende, fayalite, and a little biotite. The relative amounts of the hedenbergite and hornblende vary considerably in different specimens but the pyroxene often predominates. The hedenbergite occurs in irregular formless grains, often of good size, but again as small crystals, being most abundant as such in those varieties of the rock which possess a more

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12 U. S. G. S. Bull. 203, p. 59.
13 Washington, op. cit., p. 796.
14 Op. cit., p. 799.

distinct groundmass. The pyroxene shows an almost universal tendency to replacement by hornblende. All stages of this may be seen, from scattered shreds in the body of the pyroxene, or a little about the margins, to almost complete replacement. The hornblende is thus a later mineral formed, we believe, at the expense of the hedenbergite, by a reaction between the material of the pyroxene and the magmatic solutions during a late stage when soda, together with water and other mineralizers, were strongly concentrated. Indeed, we suspect that most, if not all, of the hornblende in all of these rocks may have been formed through a resorption process involving the preëxisting pyroxene.

The color of the pyroxene is a very light green when unaltered to hornblende. Its extinction is $\gamma = 43°$ measured on 010; optically positive, with a fairly large optic angle (estimated at from 50 to 60 degrees); $\gamma = 1.750$, $a = 1.730$. These properties point to a pyroxene near hedenbergite. This is in keeping with the fact that magnesium is too low in the rock as a whole to permit the presence of more than a very little of the diopside molecule. It is supported by the fact that hedenbergite has also been identified in the associated pegmatites. Washington calls the pyroxene of the akerite a diopside. In all slides examined by us it appears to be also hedenbergite.

The hornblende is of substantially the same character as that of the granite, deeply colored in olive-green tones, though in the akerite and syenitic phases, strong brown tones appear.

The fayalite is perhaps the most interesting mineral in the rock. While subordinate to the pyroxene and hornblende in amount, it is fairly common, although it does not appear to have been previously noted except in the pegmatites. It is present sparingly in the granites as noted, and has the same characteristics wherever found. It occurs in rounded grains, seldom with any definite crystal outline, and is generally closely associated with the hedenbergite, being apparently almost contemporaneous with it in time of formation — that is, an early mineral. It is enclosed in hornblende when this mineral is present. The grains when fresh are colorless. The indices of refraction are very high (over 1.8), the double refraction is strong (ca. 0.050); optically negative. The grains of the mineral are however seldom unaltered and frequently only reaction or decomposition products remain, but these are so characteristic that they afford unmistakable evidences of the original presence of the fayalite. Strong orange colored stains are present in and about even the freshest grains, and usually the mineral is replaced to a greater or less extent by a dark red,

and nearly or quite isotrophic material which appears to be its ordinary decomposition product. Besides this decomposition the mineral has often undergone another and more interesting transformation (the same has been noted in the case of the fayalite of the pegmatites). In this type of alteration the fayalite is replaced wholly or in part, first by a compact mass, often with a radiating structure of brightly polarizing fibers of ferroanthophyllite. Outwardly this gives place to a green, pleochroic and monoclinic amphibole probably grünerite (Part II) with an extinction of about 15°. This amphibole occurs often without the ferroanthophyllite as a border about the fayalite grains. It has also been observed that where feldspar borders the amphibole, a distinctly stronger blue color is characteristic of it. Magnetite in minute grains is thickly distributed through the ferroanthophyllite and the monoclinic amphibole. Outside of the amphibole zone comes generally one composed of a dark brown biotite.

The fayalite appears to have crystallized as a stable mineral early in the consolidation of the magma, but became unstable during a later stage, perhaps the same in which the pyroxene also became an unstable phase changing in part at least to hornblende. Under the influence of an increasing silica concentration in the magma solutions, the fayalite alters to ferroanthophyllite or grünerite. The reaction may be a simple addition of silica, but the constant presence of magnetite is suggestive of a more complicated reaction in which the magnetite is a by-product. The alkali, sodium, appears to be involved in the reaction, for we note the presence of a blue-green monoclinic amphibole and this appears to favor the fayalite-feldspar contacts, which suggests that the feldspar was also involved in the reaction.

These reaction products are not always confined to the area originally occupied by the fayalite, but tend to wander out along boundaries and cracks. The red and yellowish decomposition products noted above, also sometimes extend away from the immediate neighborhood of the affected grain, and yellowish or greenish stains extend very generally out along crystal contacts and cracks, giving the entire rock a yellowish-green color. This is apparently the main cause of the peculiar color of the rock which is the same color characterizing the nordmarkite of Ascutney Mt., Vt. Daly [15] discussed the cause of the color in this rock and ascribed it to an oxidation of the ferrous oxide contained in the feldspar to a yellowish-green ferric compound, which, with the natural gray color of the rock, gave it the peculiar

15 Daly, R. A., op. cit., p. 52.

and characteristic greenish color. Daly does not mention fayalite, but we have identified fayalite in several sections of the Ascutney rock, and they show much the same type of decomposition as is noted here. We suspect that ferrous iron-bearing solutions emanating from the decomposed fayalite crystals spread through the rock were responsible for the color which is common in rocks of this class.

Regarding the accessory minerals we may note that magnetite is common in and with the pyroxene, the hornblende, and fayalite, apparently as an original mineral. Zircon (or cyrtolite) is quite abundant and is particularly apt to occur in the form of numerous crystals in the hornblende, there being sometimes as many as fifteen or twenty crystals in a single hornblende; they have not been noted in the pyroxene. This suggests that the period of zircon formation did not begin until a relatively late stage. It may be stated here that the same thing has been noted in regard to the zircon in the Quincy granite which is, in many respects, closely related to the Rockport granite. In this connection we should also note the occurrence on Andrew's Point of a small dark and rather coarse-grained inclusion in the granite, very rich in black hornblende. The hornblende is literally peppered with small zircon crystals, distinctly recognizable under the hand-lens. We suspect that this zircon was introduced into this inclusion from solutions emanating from the granite.

Apatite is present but never abundant. Fluorite has been noted, as in the granite, usually in the hornblende or about it. Washington does not mention fayalite as being present in the variation of the quartz-syenite which he described, nor have we noted it in the syenitic phases. It seems to be confined particularly to the types richer in quartz. Washington mentions titanite as common in the akerite. This mineral has been identified only rarely in our study and appears to be present only in quantity in those phases of the rocks which are lower in their silica content (outside the present area).

Chemical Analyses.

	IV	V	VI	VII
SiO_2	69.42	68.36	66.60	65.43
TiO_2	.20	tr.	.76	.50
Al_2O_3	15.15	16.58	15.05	16.11
Fe_2O_3	1.49	.90	1.07	1.15
FeO	3.50	3.24	4.42	2.85
MnO	.10	tr.	tr.	.23
MgO	.09	.45	.36	.40
CaO	.96	1.85	2.21	1.40
Na_2O	3.35	3.97	4.03	5.00
K_2O	5.12	5.27	5.42	5.97
H_2O	.47	.35	.41	.49
P_2O_5	tr.	tr.		.33
Miscell.				.28
	99.85	100.97	100.33	100.14

IV. Nordmarkitic hornblende-granite, Cape Ann, Mass. F. L. Hamilton, Analyst.
V. Nordmarkite, Wolf's Head, near Gloucester, Mass. H. S. Washington, Analyst (op. cit., p. 800).
VI. Akerite, near Prospect Street, Gloucester, Mass. H. S. Washington, Analyst (op. cit., p. 798).
VII. Nordmarkite, Ascutney Mt., Vt. Hildebrand, Analyst (op. cit., p. 59).

The calculated mineral composition of the nordmarkitic granite (II), also that of the normal granite (I) is —

	I	II
Quartz	27.0	24.4
Microcline	32.8	30.0
Albite	33.2	32.5
Hornblende		
Pyroxene	7.0	13.1
Fayalite		
	100.0	100.0

Compared with the normal granite we see that the quartz is lower by about 3%, the feldspar by about 4%, while the dark minerals are decidedly higher, being nearly twice as abundant. The silica is somewhat higher than the limit set by Brogger for the nordmarkite, which was 67%, and although the rock is undoubtedly related in type to nordmarkites like that of Ascutney Mt., Vt., it contains so much quartz that it must be classed with the granites. On the other hand it is very closely related to the rocks from Wolf's Hill (V) and from Prospect St., Gloucester (VI), the former called a nordmarkite by Washington and the latter akerite. Its relations to the Wolf's Hill rock will be discussed later.

Fine-granite.

According to its mode of occurrence the fine-granite may be divided into four groups as follows:

First, large areas which seem to be islands in the granite such as the one on Andrew's Point which measures some hundred meters in diameter. Smaller ones occur on Davis Neck and along the coast near Lanesville and on Briar Neck near Gloucester.

Second, as inclusions varying from small patches a few centimeters in diameter to ones two or three meters across. These are found in the normal granite in many places and probably differ from the larger masses grouped under the first group only in size.

Third, forming dikes in the granite and nordmarkitic granite in several localities.

Fourth, forming a marginal zone about the pegmatite. This occurs with the pegmatite when the latter is found as rounded knots or patches in the granite as well as in dikes.

Group 1. The fine-granite on Andrew's Point varies in character within the exposure, being fine-grained and highly quartzose at the southern end and coarser and quartz-poor toward the north, where it eventually appears to pass into a quartz-syenite carrying a considerable amount of dark silicates. In the syenitic phase are found disjointed dikes of a mafic rock. This fact is of interest and importance when considered in connection with the disjointed dikes of labradorite porphyry occurring in the nordmarkitic granite along the Lanesville shore previously referred to. This will be again considered when discussing the general relations of the granitoid rocks of the area. Only the extreme types here noted will be described, but all gradations between them may be found.

The fine-grained, silicious phase is white to light gray in color,

weathering brownish or reddish-yellow. The hand specimen shows a somewhat irregular size of grain but has what may be termed a sugary texture. The feldspar is nearly white and the quartz rather bluish, both varying in size from very minute grains to those 5 mm. in diameter. The hand specimens frequently show patches of relatively coarse quartz and feldspar and not uncommonly composite patches of biotite occur. In the field a similar feature appears, where areas of coarse pegmatite a meter or more across are developed in the fine granite. In general there appears to be no definite boundary between the coarser and finer portions although in places the pegmatite occurs in angular areas with moderately sharp contacts against the fine-granite. (See Plate III, Fig. D.)

Scattered through the fine-grained portions are small flakes of biotite and hornblende. The amount is always small but these minerals appear to be never wholly absent. In the coarse, or pegmatitic portions, hornblende and biotite crystals 3 cm. or more in their largest dimension are found.

Thin sections of the finer portions show under the microscope that the size of grain and the texture are extremely irregular, the grain size ranging from 0.2 mm. to 2 mm. The essential minerals are quartz, microperthite, hornblende, and biotite. The hornblende and biotite occur in tiny flakes or shreds scattered through the rock. The feldspar is a microcline-albite microperthite, in part much crushed and disturbed and in part intergrown graphically with the quartz. Over a part of a thin section, this graphic intergrowth may be particularly striking in appearance. The quartz is rounded, subangular in outline, or in irregular rounded grains, similar to the coarser graphic-granite of the pegmatite. The intergrowth passes from one microperthite crystal to the next without apparent relation to the orientation of the feldspars. Quartz is also developed along the interstices between the feldspars and along the borders.

Biotite and hornblende occur in tiny shreds or flakes but are not associated with each other. Their appearance suggests that they have in many cases been derived from larger grains which have been torn apart and perhaps partly destroyed.

In the finer-grained, syenite phase, the grain is quite even and the mafic minerals are decidedly more abundant than in the fine granite. The dark minerals occur generally in patches one or two millimeters in diameter, each patch consisting of fine biotite flakes or hornblende crystals with more or less biotite. In the field there are no distinct boundaries between the coarse and fine phases. The coarse phase is

cut by irregular veins of aplite and pegmatite and by dikes of the normal granite.

In thin sections, the fine-grained quartz-syenite is seen to consist, like the granite, of quartz, microperthite, hornblende and biotite. The dark silicates are much more abundant than in the fine granite and the intergrowth of quartz and feldspar is much less pronounced. While there are occasional feldspar crystals from 2 to 3 mm. across, most of the feldspar is much finer (0.2) and is granulated as if from crushing. The quartz grains run from 1 to 2 mm. in diameter, are angular and interlock with the feldspar. Hornblende is quite abundant and shows what suggests in appearance an advanced alteration to biotite; the latter penetrates along feldspar crystals and forms tiny replacement veins in it. Zircon is associated with the mafic minerals as an accessory.

Group 2. The inclusions of fine-granite seem to be identical in mineralogical character with the larger masses like that just described, and we believe they have the same origin. Their outlines are sharply angular to subangular or irregular and they exhibit an irregularity of grain, frequently showing patches of truly pegmatitic character.

Group 3. The fine-granite occurring as dikes cutting both the granite and the nordmarkitic granite is mineralogically similar to the fine-granite under Group 1, although it is even in grain. It appears to be highly quartzose, an observation borne out by Washington's analysis (No. X beyond) of an alpite dike from Bass Rocks, Gloucester.[16]

Group 4. The fine-granite occurring about the pegmatite knots and as margins to certain pegmatite dikes is very similar to the fine-granite of Group 1. It will be more properly discussed under Part II which deals with the pegmatites.

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[16] Op. cit., pp. 106–108.

Chemical Analyses.

	VIII	IX	X
SiO_2	75.65	67.50	77.14
TiO_2	.10	.20	.29
Al_2O_3	13.72	16.50	12.24
Fe_2O_3	.81	.79	.29
FeO	1.00	2.76	1.04
MnO	.02	.06	tr.
MgO	.04	.09	.06
CaO	.34	1.11	.35
Na_2O	3.22	3.89	4.64
K_2O	4.30	6.09*	4.47
H_2O +	.21	.32	
H_2O –	.12	.42	.14
(F)	(.10)	(.14)	
	99.63	99.73	100.66

* This seems too high.

VIII. Fine-granite, Andrew's Point, Cape Ann, Mass. F. L. Hamilton, Analyst.
IX. Quartz-syenite phase of fine-granite, Andrew's Point, Cape Ann, Mass. F. L. Hamilton, Analyst.
X. Aplite compound dike, Bass Rocks, Gloucester, Mass. H. S. Washington, Analyst.

The fine-granite resembles the more siliceous phases of the Cape Ann granite chemically, as does also the aplite dike. The syenitic phase is lower in silica and resembles the nordmarkitic phase, particularly that described by Washington from Wolf's Hill, Gloucester.

Nordmarkite of West Gloucester.

On Shaler's map of Cape Ann he outlines a considerable area of what he terms, very properly as a field term, diorite. As seen on the map this rock extends across the river for some distance to the west into Annisquam. It is well and typically exposed on the island of Cape Ann at Wolf's Hill and all along the east side of the river. Washington who described this rock from specimens collected at Wolf's Hill called it a nordmarkite. It differs in mode of occurrence and appearance from the nordmarkitic granite which is associated with the Rock-

port granite elsewhere on the island. It differs in appearance both in the hand specimen and under the microscope from the syenitic phase of the fine-granite of Andrew's Point although it resembles this rock closely in chemical composition. From our examination of the exposures and study of this rock and its variations we are unable to arrive at any satisfactory conclusion as to just what its relations to the other igneous rocks of Cape Ann are. That it is genetically connected with them seems likely, but whether earlier, later, or contemporaneous with them we cannot determine.

The eastern part of Wolf's Hill, which is a bold, rounded hill of rock, consists of Rockport granite. Toward its western side and running across it in a generally northerly direction the granite passes suddenly but without any discontinuous contact into a strongly and rather coarsely porphyritic rock, and as we pass away from this contact to the west within a few meters the porphyritic rock gives way, also without sharp contact, to a fine-grained dark rock of dioritic appearance, which is the rock called diorite by Shaler. This rock is, however, not homogeneous, but consists of two quite distinct types. One of these is quite dark gray in color and shows hornblende alone or biotite and hornblende as the dark mineral. The other clearly cuts the former, occurring as irregular stringers and masses in it, is much lighter in color, rather finer in grain, and contains only biotite as a dark mineral.

Microscopic study shows that the porphyry has the following characteristics: coarsely and rather strongly porphyritic; phenocrysts of white unstriated feldspar, rectangular and measuring from 3 mm. to 1 cm. on a side; a few black hornblende prisms; groundmass, light gray and rather fine with biotite as the dark mineral. The phenocrysts are a cryptoperthite or microperthite, the perthitic structure being more distinct about the margins. Small rounded quartz crystals are included in the feldspars in a zone about the margin. The groundmass is fine and quite irregular in grain and consists of microcline, albite or oligoclase, quartz and biotite. The quartz forms rounded grains and is included in the microcline. Hornblende has been noted in some sections.

Nordmarkite. A typical specimen collected from a small island opposite Wolf's Hill, on the Little River, shows an even and rather fine-grained, light gray rock. An estimate of the composition is as follows: microcline 35%, sodic plagioclase 40%, quartz 12%, hornblende 12%. The microcline is in large rectangular crystals finely twinned and contains very fine lammellae of soda feldspar perthitically

intergrown. The plagioclase forms rectangular to lath-shaped crystals which are automorphic against the microcline and quartz. Its indices lie between that of the balsam and quartz, the extinction is nearly zero, indicating an oligoclase. Hornblende occurs in well-formed prisms, is pleochroic in dark olive green to yellowish-brown tones and shows an extinction of about 21 degrees. Very little biotite is present.

Another specimen collected from a ledge on the eastern shore of the Little River west of Wolf's Hill and representing the darker-colored variation of the rock, shows the same feldspars but with much less microcline and with biotite intergrown with the hornblende as in many typical diorites. An estimate of the mineral percentages made on one specimen gave: microcline 6%, oligoclase 58%, hornblende and biotite 26%, quartz 10%. The plagioclase is somewhat zoned in this type and the microcline crystals are rimmed with plagioclase.

Lighter colored type. A specimen of the lighter colored rock which cuts the darker was collected from the island west of Wolf's Hill on the Squam River. Besides being lighter in color, this rock is finer in grain. An estimate of its mineral composition gave: quartz 20–25%, microcline 70–75%, oligoclase 5%, biotite 5%. The microcline and quartz appear to be more abundant; the plagioclase is included in the microcline and is considerably seriticized. Epidote and allanite were noted, and biotite, but no hornblende is present.

These rocks differ so strongly in their characteristics from the other rocks of the area that we have a strong suspicion that they represent a separate intrusion closely connected in time with the intrusion of the Rockport granite, and probably preceding it. The absence of sharp contacts perhaps favors the view that the great mass of the Rockport intrusion engulfed an earlier rock, just as it did the nordmarkitic granite and fine-granite of Cape Ann as described by us, obliterating sharp contacts and possibly causing the development of the phenocrysts of the contact zone. This is of course purely speculation and we offer it only as a suggestion of a relationship which is in any case extremely puzzling. The rock seems to connect itself chemically (see Analyses V and VIII) most closely to the syenitic phase of the fine granite on Andrew's Point. Washington mentions a porphyritic type from Hospital Point near Beverly and on Salem Neck. We have seen in several localities a very similar rock forming dikes which are in turn cut by the alkaline syenite. This occurrence would also lead to the conclusion that the West Gloucester rock is of earlier origin than the main mass of the alkaline granites.

Inclusions.

The normal granite contains inclusions varying in size from a few centimeters to many meters. The most common varieties will be described under the following types:

I. Fine-granite.
II. Pegmatite, with and without fine granite.
III. Nordmarkitic granite.
IV. Fine to medium-grained dark inclusions.
V. Fine-grained, black, highly mafic inclusions.

Fine-granite inclusions. The material composing the inclusions of this type has already been described. The contacts are often very sharp and angular; again the rocks appear to have welded so that the contact is rapidly transitional and more or less rounded. As indicated in our discussion of the relation of the fine granite to the coarse granite, we are inclined to the opinion that all of the fine granite, except that which occurs definitely as dikes has the same origin, viz., is included in the granite magma.

Pegmatite inclusions. One remarkable inclusion of very coarse pegmatite has been found in the granite in the quarry on the Babson Farm near the end of the Cape. This was first noted by Professor Charles Palache of Cambridge and from it came the remarkable crystals of fayalite now in the Harvard University collection. This inclusion was sharply rectangular in outline and must have originally been of such size as to weigh about two tons. It consisted essentially of huge crystals of quartz and microperthite, and contained also a few large crystals of fayalite and hedenbergite, together with black mica and rare accessory minerals. Other inclusions containing pegmatite have been noted, but these have all been largely composed of fine granite. They lack the zoning characteristic of the pegmatitic schlieren found in the granite and are essentially identical with the fine granite with its pegmatite described as occurring on Andrew's Point. They are thought to have the same origin.

Nordmarkitic granite inclusions. The invasion of the nordmarkitic granite by the granite, particularly well exposed on the Laneville shore, has been described earlier. The invasion resulted in a huge breccia in which all stages of immersion in the granite may be seen. The smaller knots under Group IV are undoubtedly most of them of the same origin.

Fine to medium-grained dark inclusions. In nearly all of the

quarries in the granite are found angular to rounded patches of material, darker and finer grained than the granite. Some are evenly fine-grained, others show a porphyritic texture, due to the presence of rather large tabular feldspars in a fine groundmass. A few are comparatively coarse-grained and resemble the nordmarkitic granite. A series was collected showing all gradations from this latter type to the fine-grained type. The coarser type is found under the microscope to be identical in all essential particulars with the nordmarkitic granite previously described. Without going into detail, it may be said that a microscopic study of the various types exhibited by these "knots" indicates that they are inclusions of the nordmarkitic granite in the granite and that the differences in texture and present mineral composition can all be ascribed to the metamorphosing action of the granite magma on the original inclusion. The process of metamorphism as illustrated by this series is as follows: first, development of fine-grained quartz, albite, and microcline along boundaries between the larger microperthite crystals, together with the alteration of the hedenbergite to hornblende and biotite and of fayalite to amphibole, etc., and the mechanical crushing of the feldspar and quartz grains; second, replacement of microperthite crystals at the edges by quartz-albite material and fine-grained biotite; third, development of quartz-albite-biotite veinlets within the microperthite crystals, accompanied by further alteration of the hornblende; fourth, complete disappearance of the large feldspar grains and a further development of biotite.

Washington described inclusions of this type. He analyzed a "rather dark fine-grained specimen from Pigeon Hill quarry" and observes that "from its analogy with the analysis of rocks described below, it might be called a quartz-syenite." We give Washington's analysis together with his analysis of the nordmarkite from Wolf's Hill and ours of the nordmarkitic granite. Their similarity in chemical composition is obvious.

Chemical Analyses

	XI	IV	V
SiO_2	67.35	69.42	68.36
TiO_2	0.60	0.20	tr.
Al_2O_3	15.05	15.15	16.58
Fe_2O_3	1.23	1.49	0.90
FeO	4.76	3.50	3.24
MnO	0.05	0.10	tr.
MgO	0.03	0.09	0.45
CaO	0.55	0.96	1.85
Na_2O	4.42	3.35	3.97
K_2O	6.08	5.12	5.27
H_2O −	0.18	0.05	0.35
H_2O −	0.17	0.42	
	100.45	100.35	100.97

XI. Inclusion from Pigeon Hill quarry. H. S. Washington, Analyst.
IV. Nordmarkitic granite, Cape Ann, Mass. L. H. Hamilton, Analyst.
V. Nordmarkite, Wolf's Hill, West Gloucester, Mass. H. S. Washington, Analyst.

Dark fine-grained inclusions rich in mafic constituents. These inclusions, several types of which occur in the granite, have not been studied microscopically. They are fine-grained, sometimes feebly porphyritic, and always are very rich in biotite, and sometimes zircon. Their appearance leads us to believe that they are all of them inclusions more or less metamorphosed of basic dike rocks similar in origin to the fragments of faulted and broken dikes found in several localities and earlier referred to.

History of the Intrusion of the Igneous Rocks.

The intrusion of the igneous rocks of Cape Ann appears to have begun with an upwelling of a magma which solidified as the nordmarkitic granite although in places (Andrew's Point) it may be akeritic or even syenitic. It appears to have solidified sufficiently to have allowed of the intrusion of the labradorite porphyry dikes and others which, as noted, are now found in it. Following this, probably at no great interval, came the intrusion of the main mass of the normal

granite. This invaded the nordmarkitic granite, breaking it up and including it together with its contained dikes. Portions of it were doubtless entirely engulfed. It seems also necessary to believe that the nordmarkitic granite was rendered sufficiently plastic as a result of this intrusion to permit of its flowing and filling in about the disjointed blocks of the basic dike rocks now found in it.

Associated with the nordmarkitic granite intrusion there seems to have been a fine-granite phase, for fragments of fine-granite passing into nordmarkite or syenite are found included in the normal granite. There was also a pegmatitic phase, apparently associated with the fine-granite, for inclusions of pegmatite with and without fine-granite are also found included in the granite.

There was also a pegmatite fine-granite phase of the normal granite, of which we find evidence in the numerous blebs of coarse pegmatite with their margins of graphic-granite and fine granite scattered through the normal granite in many localities, also in the dikes and veins of pegmatitic character found in the granite, particularly in some of the quarries. There also seems to have been a later intrusion of aplite following the main granite intrusion.

Subsequently came the intrusion of the solvebergites and complementary dikes genetically related to the alkaline rocks, and still later came certain quartz porphyries of unknown relationships, and the distinctly later diabase dikes which appear generally throughout Essex County. As Clapp has shown, the alkaline intrusion in Essex County was opened by the extrusion of alkaline volcanics which are so strongly developed about Lynn, Mass., and Marblehead Neck, but all trace of any such earlier stage has disappeared from Cape Ann if it were ever present.

We may note here that there is good evidence of two distinct periods in the intrusion in the granitoid rocks along the West Manchester and Beverly shore, such as we have noted for the Cape Ann area, and the same doubtless applies to Salem and Marblehead. On the Beverly shore there are included in the coarse alkaline syenite which occurs there, basic dikes which are faulted and moved apart in exactly the same manner as are the basic dikes of labradorite porphyry near Lanesville in the Cape Ann area. The syenite here is also cut by granite. While at Beverly and Salem the history of the intrusion of the main alkaline rock types is doubtless more complicated than on Cape Ann, there is evidence, we believe, of two major periods of intrusion, an earlier one which consisted of nordmarkitic or an alkali syenite type, and a second one of a siliceous alkaline granite of the

Cape Ann, or what Clapp has called the "Peabody," type. These rocks are essentially the same, and in view of the greater importance of the Cape Ann granite commercially and the fact that it is well known as a petrologic type, we venture to suggest that it would be better to use the name Cape Ann, instead of Peabody, as a descriptive term when discussing the igneous rocks of Essex County.

PART II.

Pegmatites of Cape Ann, Mass.

The mineralogy of the pegmatites which occur with the alkali-granites of Cape Ann, Massachusetts, has been the subject of a number of papers by various authors. Recently, one of the authors (McKinstry) published a summary account of the minerals of these pegmatites.[17] It is the purpose of the present paper to deal somewhat more fully with these interesting mineral occurrences.

The authors wish to express here their indebtedness to Professor Charles Palache of Cambridge, Mass., for permission to make use of a number of observations which he has from time to time made on these pegmatites, and for the loan of a number of specimens from the Harvard collection. His kindly interest in the study of the minerals has also been of material assistance to us.

Types and Occurrence.

We may classify the pegmatite occurrences under the following heads:

I. True dikes with well-defined walls.
II. Dikes or veins without well-defined walls.
III. Rounded masses with margins of fine granite enclosed in the granite.
IV. Angular or sub-angular blocks included in the granite with or without fine-granite.

I. True dikes with well-defined walls are found in several localities. The dikes are all small, being with one exception, to be referred to below, measured in centimeters, and, with the same exception, consist of a central zone (a) of bluish, opalescent or smoky quartz, (b) a zone

[17] American Mineralogist, vol. 6, p. 56, 1921.

of pure microperthite feldspar, (c) a zone of graphic-granite often containing large lepidomelane crystals, and (d) an outer zone of fine-granite. (See Plate III, Fig. B.) Zones (c) or (d) may be lacking. For example, a pegmatite dike on Andrew's Point has a border-zone of beautiful graphic-granite one-half meter wide containing a little biotite; in another type the marginal phase consists of a fine-grained feldspar-biotite rock with little quartz, the feldspar being lath-shaped and the biotite abundant in tiny well-distributed flakes. Again, the quartz and feldspar may form a graphic intergrowth and the biotite occur in plates several centimeters in diameter, but without any particular orientation. The microscope shows that the fine-granite consists essentially of quartz, microcline or microperthite, a little albite and biotite. Pneumatolytic minerals such as fluorite and molybdenite may be present. The quartz is very often enclosed in the feldspar and there is always a strong tendency toward the graphic structure.

The exception referred to above is that of coarse-grained pegmatite some 6 meters long by $\frac{3}{4}$ of a meter thick which occurs in the granite on Briar Neck near Gloucester. This pegmatite shows no zonal structure and is noteworthy because it contains numerous large crystals of fayalite or its alteration products. Much of the fayalite is now strongly altered, but one large crystal perhaps three kilograms in weight was broken out with the hammer and a mass of unaltered mineral weighing about two kilograms was secured from the central part of the fragment. Whether this pegmatite is a true dike as it appears to be, or whether it is a great inclusion like that found in the Babson Farm quarry cannot be told with certainty from the outcrop. We suspect that it is an inclusion although it must be admitted that had we never seen the inclusion in the quarries we should not have thought of this pegmatite as being anything but an ordinary dike. If it is a true dike, it is unique in the area, both as to size and structure.

II. Narrow pegmatite veins or streaks are occasionally encountered in the normal granite. Several have been well exposed for observation in the quarries. They are generally irregularly continuous for long distances, being exposed from the bottom to the top surface of the quarry walls which in places are as much as 30 meters high. They have the appearance of being seams or openings in the granite through which mineralizing solutions or vapors have passed depositing mineral material and effecting a recrystallization and modification of the granite along their course. This mode of formation seems more plausible to the writers than to suppose that a pegmatite

solution has been forced as such into the rock and then crystallized into its present form. Their margins appear generally to lack sharp definition and to merge with the granite. The granite on one or both sides often shows strong evidences of the action of modifying solutions. It is from these veins that many of the green microcline crystals commonly found in collections have come.

III. In many places in the granite small spots may be noticed which consist of a center of coarse quartz into which penetrate crystals of microcline. When these spots attain a larger size, a zonal structure may in general be seen. The zoning is of the same type as that described above for the zoned dikes. One finds about the same variations in different spots, and the mineralogy appears to be substantially the same as in the dikes. In size they will vary from those a few centimeters in diameter to those of relatively large masses nearly a meter across. The margin of granitic material is in general relatively narrow, while the quartz center makes up the greater part of the mass. They appear, therefore, as blebs of coarse quartz margined with granitic material which outwardly merges suddenly but almost insensibly into the surrounding granite.

In the granite of Andrew's Point there is a large development of fine-granite containing much pegmatite. In part this appears to have dike-like relations to the granite and might come under Group I; again its outlines and contacts suggest that it is a large included block or blocks, or possibly huge schlieren of irregular shape. We are inclined to favor the idea that it is an included block, particularly in view of its close association with patches of the nordmarkitic granite and its strong resemblance to some undoubted inclusions in the near-by quarries.

In the narrower portions of this fine-granite the quartz and coarse feldspar seem to occupy a central position with fine-granite outside, but where the fine-granite is greater in amount the coarse-grained portions seem to occur without any particular method of arrangement. They form isolated areas of varying size up to those over a meter across (see Plate III, Fig. D), with sharp and somewhat irregular contacts, and consist of large microperthite and quartz crystals related to each other texturally just as in the ordinary granite the quartz in general predominates in amount and is of the opalescent variety. All together they present a rather striking appearance. While one is conscious of the very great contrast in grain as compared with the fine-granite host one cannot altogether escape the impression that the difference must after all be brought about by some rather slight differ-

ences in physical conditions at the time of crystallization; the fine-granite always seems about to pass into coarser pegmatite for one notes here and there a sudden variation in the fine-granite in the direction of a coarser texture.

IV. Angular or subangular inclusions of fine-granite and of fine-granite with a variable amount of pegmatite are found in the normal granite, and one large and remarkable inclusion of coarse pegmatite has been found, as noted earlier. These are undoubtedly inclusions of a pegmatitic phase which accompanied or followed the first invasion of the alkaline magma, which as noted, was in the main nordmarkitic in character.

Attention was first directed to the large inclusion of coarse pegmatite in the granite of the quarry on the Babson Farm by Professor Charles Palache. The best specimens from it are now in the mineralogical collection of Harvard University. This inclusion was rectangular in outline and its original dimensions must have been 2 by 1 by 1 meters. It consisted of very large crystals of quartz and microcline-microperthite with occasional large crystals of fayalite and hedenbergite, or their decomposition products, lepidomenale together with accessories such as ilmenite and several rare minerals. The material of this included mass is the same as that of the fragments of fayalite with attached feldspar and quartz which were found in the Rockport quarry many years ago and described by Penfield and Forbes and somewhat later by Warren. This material, though never seen in place, is, from its appearance and the attached granite, believed to be an inclusion similar to the one described above.

Mineralogy of the Pegmatites.

Beyond is given a complete list of the minerals occurring in these pegmatites. Many pegmatite minerals typical of the less alkaline rocks are entirely absent here. Among these many be mentioned tourmalin, beryl, lepidolite, garnet, and muscovite. The mineral association is that of an alkaline granite pegmatite in which the iron is high, magnesium low, and boron absent. Hence we have lepidomelane in place of muscovite or biotite, cryophyllite in place of lepidolite, and danalite instead of beryl.

Analogous localities. The pegmatites of Quincy, Mass., occurring in a granite closely related to the present one in type, present certain features in common but also some striking differences. The Quincy pegmatites carry acmite and riebeckite without lepidomelane; the

Cape Ann, alkali-hornblende, hedenbergite, lepidomelane, and fayalite. Structurally the main pegmatites of the Quincy granite are pipe-like and have open cavities, features not found on Cape Ann. The zonal arrangement as described by Warren [18] for the Quincy pegmatites is similar however to that found at Rockport, and like the latter, the Quincy also carries rare-earth minerals, although different in type.

Some resemblance is indeed to be expected in similar stocks or batholiths of the same petrographic province. It is interesting to note, however, the analogy in occurrence at a remote locality, the famous Barringer Hill in Texas, which seems to be a pegmatite body somewhat analogous to the Rockport type but magnified to enormous proportions, as the following extract from a description of the Texas locality will show: [19]

"At the edge of the intrusion is a graphic-granite of peculiar beauty . . . the feldspar is an intergrowth of microcline and albite, (1) in large masses . . . (2) as huge crystals, many of which have one or more sharply defined edges, especially where surrounded by quartz.

"Ilmenite occurs in radiating bunches of sheets or blades. The mica . . . is reported to be close to lepidomelane in composition. Small flakes of lithia mica are found" (whether this is lepidomelane or cryophyllite is not stated) "no muscovite was seen, though it is said to be found occasionally.

"Cyrtolite is rather common . . . in polysynthetic groupings with curved edges."

Other minerals common to the two localities are: allanite, fergusonite, magnetite, smoky quartz, pyrite, sphalerite, molybdenite, and gadolinite.

The following minerals are definitely reported as absent at Barringer Hill and all of them are also absent at Rockport: tourmaline, zircon (though cyrtolite is common at both localities) beryl, monazite, cassiterite, and tungsten minerals.

Hidden [20] describes as very conspicuous the radial lines or "stars" about the rare-earth ore masses at Barringer Hill, a phenomenon very characteristic about the "strained zones" surrounding the cyrtolite and gadolinite crystals at Rockport.

The pegmatite minerals of the Cape Ann granite may be grouped as follows:

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18 Warren, C. H. Am. Jour. Sci., vol. 28, p. 449, 1919.
19 Hess, U. S. G. S. Bull. 340.
20 Hidden, W. E. Am. Jour. Sci., vol. 19, p. 425, 1905.

a. Essential, major constituents.
- Microcline
- Albite
- Quartz
- Lepidomelane

Subordinate constituents.
- Hedenbergite
- Hornblende
- Fayalite

b. Minerals characteristic of pneumatolitic processes.

Element	*Represented by*
F	Fluorite
Li	Cryophyllite
Rare-earths, Ti, Nb, Ta, etc.	Cyrtolite Allanite Fergusonite Yttrocerite Tantalite Thorite Gadolinite
Ti	Ilmenite
Mo	Molybdenite
Pb	Galena
Zn	Sphalerite
Be	Danalite
Fe	Pyrite Pyrrhotite

c. Secondary minerals.

Formed at high temperatures.
- Grünerite
- Ferroanthophyllite
- Chlorite

Formed at low temperatures.
- Sphalerite
- Siderite
- Calcite
- Hematite

Final products of oxidation
- Limonite
- Kaolin.

Feldspars. As already mentioned the feldspar of the pegmatite is chiefly a microcline-microperthite. In places the feldspar approaches amazon stone in color and shows crystal planes, particularly where surrounded by quartz. More commonly the feldspar is gray or greenish-gray. In some of the pegmatites of Group IV the feldspar is somewhat platty in habit with a strong tendency toward curved cleavage surfaces. Frequently it includes plates of lepidomelane and ilmenite or is fractured and carries stringers of black chloritic material.

The curved feldspar from the included pegmatite in the Babson Farm quarry occurs in masses of considerable size and presents a curious appearance; perhaps it may be said to resemble a curved shell as nearly as anything. In basal section, under the polarizing microscope (see Plate V, Fig. B) the traces of the 010 composition planes, instead of being parallel, are seen to radiate slightly, forming long narrow segments that extinguish successively as the stage of the microscope is rotated through a small angle. The traces of the basal cleavage change their direction slightly in each segment, the aggregate forming the curved surfaces seen in the broken fragments. The albite member of the microperthite follows the usual mode of intergrowth in each segment. Included in the feldspar are tiny greenish needles, orientated in the direction of the edge 010–001. They resemble amphibole, but are so small that their properties could not be determined.

Quartz. Quartz occurs (1) in graphic intergrowth with feldspar, (2) in large masses, usually at the center of the pegmatite. The quartz is usually fractured or shattered and varies in color from that which is clear and glassy to that which is blue, purplish, or smoky. The large masses found in the Babson Farm quarry showed a very beautiful bluish to purplish opalescent tint. This variety when heated becomes filled with minute cracks, and splinters are spalled off with violent decrepitation. Quartz in distinct crystals occurs only as a secondary product.

Micas. The most common mica is lepidomelane. The lithia mica, cryophyllite, appears to be quite rare. It is distinguished by greater fusibility, stronger lithium flame, greener color and the greater elasticity of its plates. Since much of the lepidomelane also gives a lithium flame, it is probable that it contains admixed cryophyllite in small quantities.

Phlogopite has been reported by Sears, but the writers are inclined to question the accuracy of this report, since a highly magnesian mica would not be expected here.

For comparison the optical properties of the micaceous minerals of the pegmatites are tabulated:

	Lepidomelane	Cryophyllite	Chlorite	"Chlorotoid"
Color in basal section	grayish green	apple green	grayish-green	brown
Pleochroism	olive green to brown (none in basal section)	apple green to brown	same	dark brown to colorless
β	1.656	1.56	1.677	1.67
α				1.57
Biref. in basal section	very low	very low	very low	
2 E	very small	57°	55°	very small
Optic Sign	(−)	(−)	(−)	(−)?

Lepidomelane occurs in the pegmatite in large tabular masses up to a decimeter in diameter and 35 mm. in thickness. It was early noted by Cooke[21] in describing cryophyllite from this locality, and was named "annite" by Dana. In 1886 Clarke,[22] who published analyses by Riggs and Cooke, discussed its probable formula as deduced from the analyses. It is brilliant black in hand specimens, rather brittle and gives a greenish-black streak. In thin section, basal cleavage flakes are grayish-green and show double refraction. The optic angle is very small and scarcely any separation of the hyperbolae is discernible. β is close to 1.656, hence considerably greater than in ordinary biotite.

One mass of lepidomelane on the border of a large pegmatite body shows considerable granular magnetite between its foliae associated with chlorite. Some plates of lepidomelane end abruptly against magnetite, while others continue through it. Isolated shreds of lepidomelane are enclosed in the chlorite-magnetite mixture. The

21 Cooke. Am. Jour. Sci., vol. 43, pp. 217, 230, 1867.
22 Clarke, F. W. Am. Jour. Sci., vol. 37, p. 358, 1889.

relations suggest that the lepidomelane has been replaced along the cleavage directions by the magnetite and chlorite.

Some of the lepidomelane shows replacement and injection by quartz, sphalerite, and fluorite. One thin section showed fine needle-like crystals probably of ferroanthophyllite, extending from lepidomelane into quartz and another shows a granular alteration rim of chlorite between feldspar and mica, stringers of chlorite running off into cracks in the feldspar.

The cryophyllite occurs in plates in the feldspar, with which it apparently crystallized simultaneously. Its physical and optical properties have already been mentioned. The optic angle (2E) was found to be 57° which agrees substantially with Dana's value of 56.

Fayalite. The occurrence of large crystals of fayalite several kilograms in weight in these pegmatites has already been mentioned. They invariably show more or less alteration, part of which is due to weathering but the greater part to reaction with magmatic or late mineralizing solutions. The mineral changes which have occurred in the fayalite of the pegmatites are substantially the same as those seen in the thin sections of the granite and the nordmarkitic granite. The fayalite forms only rough crystals, is of a very dark, oily green to almost black color, and appears to have contained some finely divided magnetite as an original impurity. The composition as found by Penfield and Forbes is as follows:

	I	II	Average	Ratio		
SiO_2	30.11	30.05	30.08	.501		1.00
FeO	68.04	68.19	68.12	.946		
MnO	.77	.65	.72	.010	1.004	2.00
H_2O	.88	.87	.80	.048		
	99.80	99.76	99.72			

Specific gravity 4.323, 4.316. Average 4.318.[23]

About the margins and to a greater or less extent throughout the body of the crystals along cracks and cleavages, there is very apt to be alteration which appears to be in part, at least, limonitic in character, and to be the result of surface alteration. In places (the Briar Neck

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23 Am. Jour. Sci., vol. 1, p. 129, 1896.

pegmatite in particular) the fayalite crystals have changed almost entirely to a limonitic mass.

Two somewhat different types of reaction products have been noted surrounding the fayalite. These, however, probably grade into each other. The first is that described earlier by Warren, and consists of a narrow border of radiating fibers of what he described as an iron-rich anthophyllite but which should now be called ferroanthophyllite.[24] With this is associated a considerable amount of fine magnetite which appeared to be segregated thickly about the outer edge of the fayalite and where the ferroanthophyllite makes its beginning. (See Plate V, Fig. A.)

The other type of reaction which our recent study shows to be probably more common, is as follows: (1) a zone, in one instance 3 mm. wide, of matted greenish to colorless amphibole crystals with much disseminated magnetite; (2) adjoining this on the outside is a zone of about equal width of matted biotite shreds with some greenish hornblende; (3) microcline-microperthite of the curved habit and carrying small stringers of quartz. The amphibole of (1) is colorless to very faintly pleochroic and forms rather stout bladed crystals instead of the needle-like habit of the anthophyllite. The extinction angle is close to 15°; its index of refraction was found by the immersion method to be above 1.67, and therefore too high for tremolite or any other non-pleochroic amphibole except grünerite. Here, as seems to be also the case in the granite and nordmarkitic granite, the reaction products appear to differ according as the fayalite borders on quartz or on the feldspar. If quartz was originally in contact with the fayalite, the reaction product is the ferroanthophyllite and magnetite; if the feldspar adjoined the fayalite, then we find the amphibole and biotite with magnetite. The presence of the alumina and alkali in the feldspar are doubtless responsible for the differences, so that it seems probable that the adjacent mineral took part in the reaction under the influence of the active solutions emanating from the surrounding rock. It seems to have been a reaction which took place in situ. The magnetite associated with the grünerite is in part, at least, secondary, since it clearly replaces the grünerite along fracture and cleavage directions. Along narrow fractures well within the fayalite, magnetite and grünerite are developed in long stringers. The reactions here noted would seem at first thought capable of representation by rather simple equations expressing the conversion of an orthosilicate to a metasilicate. The presence of magnetite,

24 See Shannon, E. V. Proc. U. S. Nat. Museum, vol. 59, p. 397, 1921.

however, complicates the matter and it seems idle to attempt to express the reaction in detail.

Fluorite. Crystals of sea-green fluorite as large as 3 cm. in diameter are sometimes found embedded in the feldspar and apparently of early formation. Purplish fluorite occurs and is usually associated with granular chlorite and metallic sulphides.

Pyroxene. Crystals of pyroxene are not uncommon. The usual habit is that of a twin flattened parallel to the orthopinacoid, the basal partings meeting at an angle along this plane. These crystals are embedded in the feldspar. Qualitative as well as optical examination shows that this pyroxene is hedenbergite. The crystals are frequently heavily altered to limonite.

Hornblende. This mineral occurs as a marginal development about the pyroxene and is an alkalic variety.

Ilmenite. This mineral occurs in plates or in narrow veins in the feldspar, associated with granular chlorite which frequently coats the surface of the ilmenite adjoining the feldspar. Pyrite has been noted with the ilmenite along the feldspar contact.

Cyrtolite. The cyrtolite forms small groups of brown tetragonal crystals having curved faces and is usually associated with scattered white quartz and granular black chlorite.

Tantalite. Tantalite has been found by Professor Palache in the form of a prismatic crystal about 25 mm. long embedded in feldspar of the graphic-granite zone. The front and side pinacoids were well developed and were terminated with domes and by the basal pinacoid.

Thorite. This mineral occurs as the variety orangite and is associated with fluorite.

Fergusonite. Fergusonite occurs in the form of small irregular grains and narrow lens-shaped plates in the feldspar with the curved-plate habit, and also in the graphic-granite. One slender crystal 15 mm. in length was found in the feldspar. In another specimen from a zone of large mica plates, fergusonite is marginal on cyrtolite.

Gadolinite. A crystal 1 by 2 cm. embedded in a "strained zone" in the quartz was collected by Professor Palache and corresponds closely to the description of this mineral from Llano County, Texas. It is dark, lustrous and glassy, with a conchoidal fracture, black in ordinary light, but green in thin splinters by transmitted light. The crystal is rounded in outline with no well-defined faces, and is coated with a brick-red alteration product.

Yttrocerite. This mineral is reported by Sears [25] from Rockport on massive quartz.

[25] Op. cit.

Molybdenite. Molybdenite occurs in flakes up to 12 cm. in diameter, although it is usually of much smaller size. It appears to favor the outer zone of the pegmatite bodies, where its characteristic mode of occurrence is in the feldspar containing large biotite crystals. It is often found in the fine-granite masses which contain no pegmatitic material at the center. Purple fluorite is a constant associate, though the two minerals are rarely found in contact. A granular black chlorite is also a companion mineral. In one specimen, flakes of molybdenite were noted in the chlorite which forms a small vein in fayalite alternation products.

Sulphides. Galena, sphalerite, and danalite are all found in similar associations, i. e. surrounded by quartz and particularly feldspar. The grains or masses of the sulphide minerals are separated from the feldspar by sharp walls, usually parallel to the crystal or cleavage planes. Well-formed crystals of feldspar were noted completely surrounded by danalite and in other cases by sphalerite. Usually the surface of the feldspar is corroded and discolored by minute chlorite flakes. Sphalerite also occurs in small stringers with chlorite, penetrating fractures in the feldspar.

Where galena and sphalerite occur together, galena is usually enclosed in the sphalerite and does not form stringers or veinlets in the gangue minerals. Polished sections show the galena replacing sphalerite in irregular veinlets, one vein enclosing a minute "horse" of sphalerite. Pyrite and pyrrhotite occur very sparingly, sometimes in poorly defined grains along the periphery of the crystals of the dark silicates such as fayalite and pyroxene. Pyrite was observed filling cleavage cracks in sphalerite and forming thin films in factures in bluish quartz.

Danalite. Rockport is the type locality for this mineral which was first described by Cooke.[26] It occurs in small grains to large masses, pink in color and usually irregular in shape, although rarely it shows a suggestion of octahedral form. The mode of occurrence resembles that of the sphalerite in (1) angular walls against feldspar, (2) surrounding of feldspar crystals, (3) association with galena and chlorite. Often danalite and sphalerite are found in contact, in which case the sphalerite is marginal on the danalite. Evidently the minerals were deposited by solutions containing silica and metallic sulphides. Where beryllium was present, and as long as it lasted, danalite was formed. In the absence of beryllium, sphalerite seems to have been the mineral deposited.

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[26] Cooke, J. P. Am. Jour. Sci., vol. 43, p. 75, 1866.

Magnetite. Magnetite in small grains is found as an original mineral in the fayalite, possibly elsewhere. It is common as the result of the alteration of the fayalite and lepidomelane as elsewhere noted.

Chlorite. The occurrence of black chlorite as a decomposition product of the lepidomelane and an associate of the sulphides has already been alluded to. It is easily fusible, often exfoliating like a vermiculite, yields much water on heating and frequently gives a small lithia flame coloration. There appear to be all gradations between lepidomelane and fine-grained chlorite.

A similar form of chlorite is found in compact masses of long, narrow pseudo-hexagonal crystals a few millimeters in diameter. Cyrtolite is frequently embedded in this variety and the chlorite often forms embayments into the cyrtolite as well as into the adjoining feldspar. Flakes of the chlorite are grayish-green by transmitted light, optically negative with an optic angle, 2E = 55°, while the index of refraction for the rays vibrating parallel to the plane of the cleavage is 1.67.

Chlorotoid. A black, cleavable mineral somewhat resembling hornblende in appearance, but showing only one cleavage, is frequently noted associated with chlorite and fluorite. Often it is seen in irregular masses, containing fragments of feldspar, thus forming the cementing material of a veritable breccia. This mineral was labeled "chlorotoid" in the collection of Harvard University, and is quite similar in appearance to the masonite from Rhode Island. The mineral was studied with a view to obtaining a more accurate identification but was found not to correspond to any described species. It is strongly plechroic, dark brown to colorless. The mineral is very opaque and attempts to make a thin section were not successful. Tiny grains, however, show high interference colors at their edges. The indices of refraction as determined by the immersion method were found to be $\alpha = 1.67$, and $\gamma = 1.57$, which would give a birefringence in the neighborhood of 0.10. Fragments are positively elongated. In thin sections of one of the fine-granites, a mineral having a similar color and pleochroism was noted and this afforded an interference figure which was apparently uniaxial and negative in optical character.

The mineral fuses with difficulty to a black magnetic globule, giving no lithium flame. It is not decomposed by sulphuric acid. A qualitative analysis gave much iron and aluminium, but no calcium nor magnesium.

Except for the high indices of refraction, the optical properties correspond to a biotite high in iron, but the mineral in question does not have a cleavage like a micaceous mineral.

Astrophyllite. Reported by Sears but not identified by us.

Ferroanthophyllite and *Grünerite.* These minerals have already been described as to occurrence and characters under the description of the alteration products of the fayalite.

Calcite. Calcite occurs in film-like plates along cleavage planes in decomposed pyroxene.

Quartz (secondary). Flattened crystals are found showing prismatic and terminal planes in decomposed pyroxene.

Phenacite and the decomposition products of Danalite. Palache[27] has described an interesting series of decomposition products of danalite from a quarry along the railroad between Rockport and Gloucester. Phenacite occurs in small crystals up to 5 mm. in diameter lining cavities, together with pale brown anhedral crystals of siderite, imperfect sphalerite crystals, minute pyrite crystals showing the faces of the cube and octahedron, and hematite in lustrous scales or as red stains on quartz crystals.

Kaolin and *Limonite.* These minerals are mentioned for the sake of completeness and are the final products of weathering of the feldspars and the dark silicates respectively.

Associated with the limonite in the somewhat tabular masses which form the decomposition products of the fayalite and pyroxene where these minerals have suffered decomposition on a large scale, is a yellowish to reddish-brown mineral with a conchoidal fracture which has not been identified. It is nearly or quite isotropic, index about 1.60, streak brown but lighter than that of limonite. In hydrochloric acid it loses its color and the acid reacts for iron and a trace of calcium. It is doubtless a mixture of iron oxides.

Xanthosiderite. This mineral has been described by Sears as occurring in segregated masses, and with a botryoidal habit in crevices at the Rockport Granite Company's quarry. We have not verified this occurrence.

Paragenesis of the Pegmatite Minerals.

From what may be observed regarding the mode of occurrence, structure, and composition of the pegmatite bodies it seems clear that they represent a fraction of the granitic magma produced by the normal progress of crystallization of the magma, and that they differ from the original magma chiefly in the greater concentration of silica, certain rarer elements and probably in water or water vapor.

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27 Palache, C. Am. Jour. Sci., vol. 24, p. 249, 1907.

Some portions remained near their place of origin and eventually formed the pegmatitic segregations of a generally rounded form. Other portions, of larger size, were forced away from their places of origin and formed larger and more irregularly outlined bodies in the granite or were intruded into portions of the granite already solidified forming dikes or dike-like masses with true cross-cutting relations. Those pegmatites which were associated with the first and nordmarkitic intrusion were involved in the general breaking and inclusion of that rock in the later normal granite and now appear as inclusions in it. We may also suppose that from deeper portions of the granite mass as it continued to crystallize, further portions of the same more pegmatitic fraction continued to be given off and these forced or worked their way upward and out along lines of weakness, fractures or cracks in the rock mass above and produced, partly by the recrystallization of minerals already formed along the line or path of escape, and partly by further deposition of dissolved mineral material, the pegmatitic streaks or veins which, as we have noted, are characterized by irregular boundaries and lack of sharp and definite contacts with the containing rock.

Once a body of this pegmatitic fraction became individualized in the rock mass with crystallization not yet fully completed, we may conceive of its continuing the crystallization process without break in continuity but with such differences in sequence of crystallization and texture as were imposed by the somewhat different state of chemical and physical equilibrium which would necessarily obtain in such a fraction of the magma as we have pictured. The main characteristic of the outer portions of the pegmatite bodies, whether in the form of rounded masses or of dikes, appears to have been the simultaneous crystallization of the quartz and feldspar, either as fine granite or as an intergrowth. Why either one or both of these should have formed no one knows. They are undoubtedly very closely related and whatever the determining factor or factors are which produced one or the other, they are, we must suppose, small in magnitude. Some slight variation in physical condition, such as a brief period of supersaturation; some small variation in the chemical composition, perhaps the presence or absence of some constituent possessing extraordinary potency in its effect on crystallization may have been the cause or causes in question. It is perhaps not inconceivable that the fine granite was produced by the reaction of a highly active solution in the center of the mass on the original wall granite. At some period after the outer portions of the pegmatite were formed, substantially as we

see them, there was a time during which coarse quartz and feldspar formed along with fayalite, lepidomelane and pyroxene, and this period seems to have ended, or come to a pause, with the exhaustion of the feldspar content and a very great, indeed almost exclusive, concentration of silica in the center of the pegmatite. That this silica solution contained a certain amount of other material, and that mineralizing activity continued after the surrounding rock had formed is evidenced by the fact that sulphides are found in the quartz and that they and other mineral compounds were introduced into the feldspar, etc., at a very late stage.

The fayalite became stable and crystallized at an early stage in the pegmatite as well as in the granite and nordmarkitic granite. It appears to have given place to pyroxene and this to hornblende and mica. Doubtless some part of it was reabsorbed, the other minerals appearing. Much of it was able to persist, although in part destroyed by late magmatic or postmagmatic reactions, forming the ferro-anthophyllite, grünerite, and magnetite as has been described.

The sulphides, as noted, occur in the quartz centers, and are persistently associated with fluorite and black chlorite which penetrates fractures in the feldspar, and therefore these minerals are believed to belong to a late stage of formation. Evidently solutions, probably the last remaining liquor after most or all of the pegmatite material had crystallized, permeated the feldspar and aided by slight fracturing attacked the lepidomelane and converted it into chlorite and magnetite, at the same time depositing galena, danalite, and purple fluorite. Pyrite also belongs to this late stage, since it occurs in fractures in quartz and sphalerite.

The relation of these sulphides is of interest from the standpoint of ore deposition. In many descriptions of the successive generations of sulphides, the process is pictured as a series of invasions by hydrothermal solutions of differing composition. While such a process may have been followed in some localities, it appears that here, since there are no channels connecting the pegmatite bodies with deep or distant sources, the ingredients of the minerals of this later generation must have been concentrated in the pegmatitic fraction; for if sulphides passed through the almost completely solidified granite, either in gaseous or liquid solution, we should expect to find some alteration and deposition of sulphides in the surrounding rock. Hence it seems reasonable to suppose that the galena and pyrite, while evidently later than the sphalerite, were not imported at successive stages, but merely precipitated more tardily than that mineral.

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ILLUSTRATIONS.

PLATE I.

Generalized geologic map of eastern Massachusetts. (On this map the alkaline granites are called "Quincy granite.")

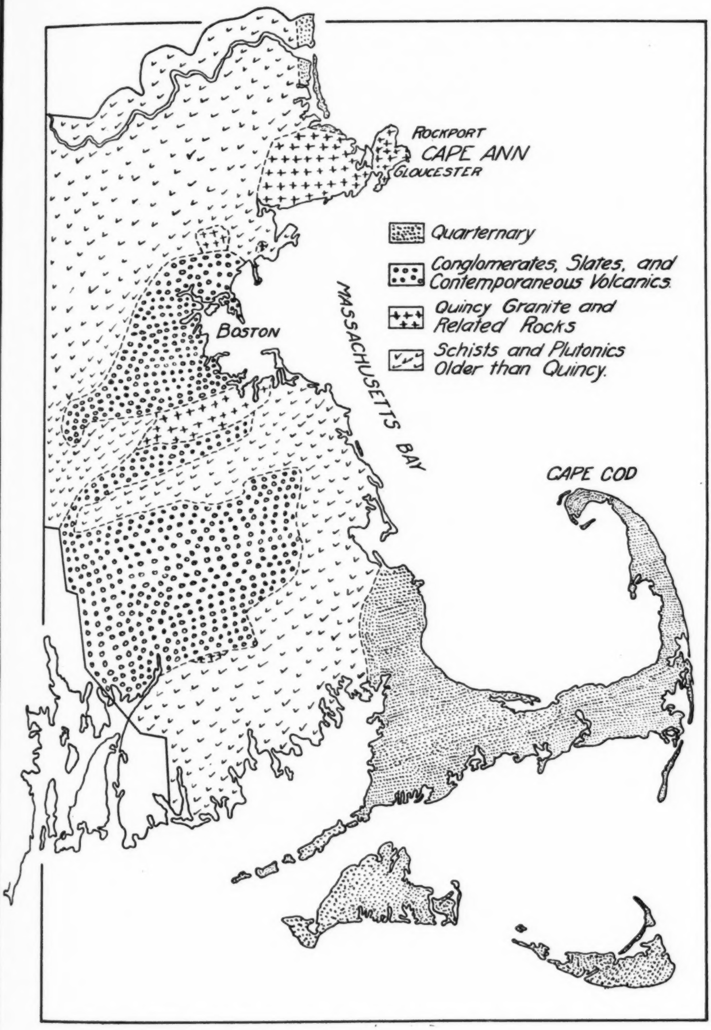
ROCKPORT
CAPE ANN
GLOUCESTER
Quarternary
Conglomerates, Slates, and Contemporaneous Volcanics.
Quincy Granite and Related Rocks
Schists and Plutonics Older than Quincy.
BOSTON
MASSACHUSETTS BAY
CAPE COD

PLATE II.

Detailed geologic map of Andrew's Point, Cape Ann.

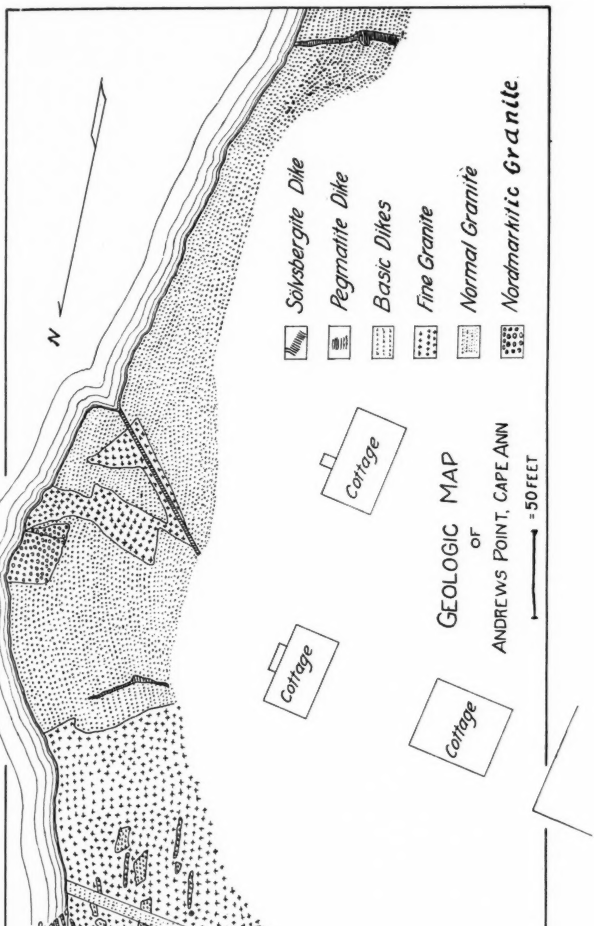
GEOLOGIC MAP
OF
ANDREWS POINT, CAPE ANN
=50 FEET
Sölvsbergite Dike
Pegmatite Dike
Basic Dikes
Fine Granite
Normal Granite
Nordmarkitic Granite
N
Cottage
Cottage
Cottage
Low Tide Line

PLATE III.

FIGURE A. Fragments of nordmarkitic granite in normal granite.

FIGURE B. Pegmatite dike with quartz center and fine-granite margin cutting granite. Western coast near Bay View.

FIGURE C. Granite dike (light) cutting nordmarkitic granite near Bay View, west coast.

FIGURE D. Coarse pegmatite in fine-granite. Andrew's Point, Cape Ann.

Fig. A

Fig. B

Fig. C

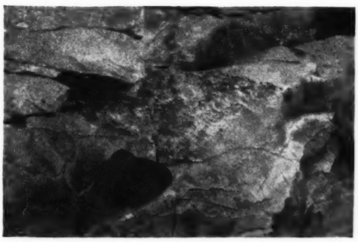

Fig. D

PLATE IV.

FIGURE A. Labradorite porphyry dike fragments included in nordmarkitic granite (light) near Bay View, west coast.

FIGURE B. Fine-granite and pegmatite dikes cutting nordmarkitic granite, ¼ miles southwest of Lanesville.

FIGURE C. Faulted and displaced trap dike in syenitic phase of fine-granite, Andrew's Point.

Fig. A

Fig. B

Fig. C

PLATE V.

FIGURE A. Fayalite (f) changed along contact with quartz, to ferro-anthophyllite (a) and magnetite grains (black). From pegmatite, Rockport quarry. Photomicrograph, crossed Nicols, × 20.

FIGURE B. Basal section of microcline-microperthite of the "curved-plate habit." From large pegmatite block in granite, Flat Ledge quarry. Photomicrograph, crossed Nicols, × 20.

FIGURE C. Thin section, Cape Ann granite. Shows fine-grained quartz and albite along the margins of the microperthite. Photomicrograph, crossed Nicols, × 30.

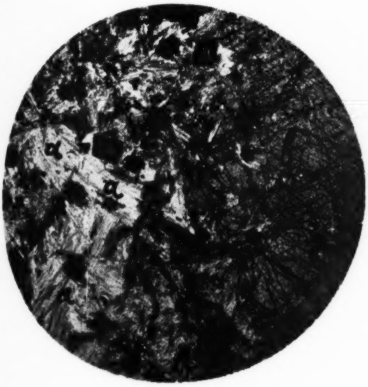

FIG. A

FIG. B

FIG. C